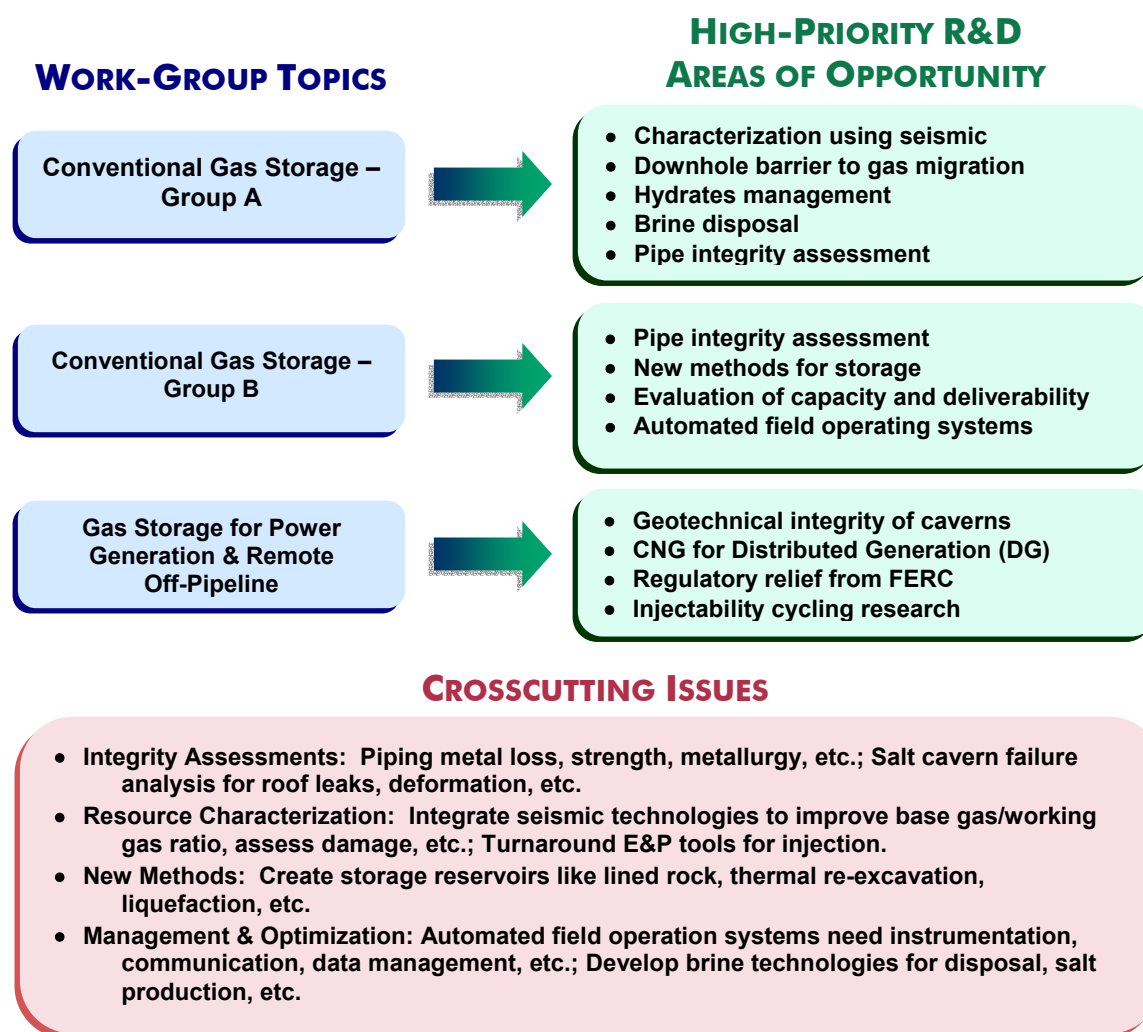


## Work Group Products

Following the plenary session presentations, the participants worked in three breakout groups, two for conventional gas storage and one for gas storage for power generation and remote off-pipeline. The three groups working in parallel identified:

- ◆ Key barriers to improved natural gas storage
- ◆ R&D opportunities/needs to overcome the barriers, and
- ◆ Implementation Strategy for priority R&D topics including component R&D activities and steps; capabilities, tools, facilities, and resources; collaborations, partners, and government role; geographic benefits; and impacts for deliverability and cycling, cost savings, safety and security, capacity, environment, and reliability.

Figure 1 provides an overview of the work group results. The detailed results follow.



**Figure 1. Overview of Gas Storage Workshop Results**

### 3.1 CONVENTIONAL GAS STORAGE – GROUP A

Reservoir characterization and management received the most focus. The former emphasized cheaper seismic or other methods to identify gas in-place, while the latter advanced barriers to gas migration and hydrates prevention. Both would have a maximum impact on capacity.

#### TECHNOLOGY BARRIERS

Barriers feedback from the group was easily categorized under seven major headings: reservoir characterization, damage at wellbore and injectivity, reservoir management, changing market conditions, salt/rock caverns, drilling technology, and integrity.

#### R&D NEEDS

The R&D needs to overcome barriers used all of the same topic headers from barriers except changing market conditions and added three new categories, gas processing, remote sensing and control, and other. Participants prioritized opportunity needs using one top vote and four regular votes. Under reservoir characterization, the need for seismic technology applications was the only one to receive four top votes. Two needs received a total of two top votes plus four regular votes: develop means of preventing/dealing with hydrates formed during operations and better means of assessing remaining strength (integrity). Another two needs received one top vote and four regular votes: develop a downhole barrier to gas migration and brine disposal. All of these opportunity needs were carried over to the implementation strategy for specific actions.

#### ACTIONS

The group produced lists of activities for each of the top five priority opportunities, along with capability requirements, collaborations, geographic benefits, and a set of impact gauges. However, funding requirements were not ascertained. Collaborations generally will involve storage operators along with E&P and service companies. Government roles would be for funding and technology sharing, and geographic benefits would be widespread.

#### Participants: Conventional Gas Storage – Group A

NAME	ORGANIZATION
Nathan Anderson	El Paso Corporation
Steve Bauer	Sandia National Labs
Karen Benson	CMS Panhandle Companies
Ken Brown	Hoblitch Reservoir Technologies
Branko Damjanac	Itasca Consulting Group
John Finkbiner	Union Gas Limited
Steve Foh	Gas Technology Institute
Brian Hall	Equitrans, L.P.
Glenn Knepper	International Gas Consulting
Jim Mansdorfer	Southern California Company
Mike McCall	Conversion Gas Imports, LLC
Fred Metzger	DTE MichCon
Daopu Numbere	University of Missouri – Rolla
Joe Ratigan	PB-KBB, Inc.
Ken Squire	Halliburton Energy Services
Gary Sypolt	Dominion
Brad Tomer	DOE/NETL

\*Report out presenter

**FACILITATOR:** Jack Eisenhauer, Energetics

**WRITER:** Jennifer Cordero, Energetics

**CONVENTIONAL GAS STORAGE – GROUP A**  
**Exhibit 3.1.1 Technology Barriers to Improved Natural Gas Storage**

Reservoir Characterization	Damage at Wellbore and Injectivity	Reservoir Management	Changing Market Conditions	Salt/Rock Caverns	Drilling Technology	Integrity
<p>Cheaper 3-D seismic</p> <p>Seismic or other technology to better identify gas filled porous bodies in reef structures</p> <p>Formation properties such as heterogeneities not well characterized</p> <p>Mechanical and hydrological characterization of rock mass</p> <p>Geological assessment of southeastern U.S. structures compatible with storage</p> <p>Low cost, 4-D seismic or other method to identify gas in-place at end of season</p> <p>Logging horizontal wells</p> <p>Differences in flow properties of gas during injection and production, i.e., hysteresis not well understood</p>	<p>Lack of chemical, minimally intrusive diagnostic techniques to accurately identify good stimulation candidates</p> <p>Determination of when/where damage occurs (injection vs. withdrawal vs both)</p> <p>Non-Darcy (i.e., turbulent) skin damage in high rate storage wells limits peak rates (turbulent flow in reservoir)</p> <p>Reduce cost of wellhead filtration</p> <p>Find best technology to best remove skin damage in wells</p> <p>Improve well injectivity</p> <p>Application of frac pac technology to thick, high permeability, unconsolidated sandstone reservoirs.</p>	<p>High levels of cushion gas to cycled gas</p> <p>Lower cost cushion gas replacement</p> <p>Quantify the pressure limits in a reservoir</p> <p>Improvement of working gas to base gas ratio in aquifers</p> <p>Low cost H<sub>2</sub>S removal</p> <p>(Deliverability) – understanding gas hydrates</p> <p>Low cost, low O&amp;M measurement and control technology for individual well pressure and flow measure, with oil, water, sand (+/- 10%); remote control</p> <p>Injection</p> <ul style="list-style-type: none"> <li>– Cycling required in future</li> <li>– Maintenance/supply</li> </ul> <p>Accurate assessment of full field potential to optimize working gas, feeding value, etc.</p> <p>Inventory verification</p> <ul style="list-style-type: none"> <li>– Accurate method</li> <li>– Little downtime</li> <li>– No time for shut-in</li> </ul>	<p>Strategically located underground space</p> <p>Injection season is too long</p> <p>Proper valuation of different storage services</p> <p>Conservative nature of LDC's – low tolerance of risk – high storage balances</p> <p>Transmission infrastructure into/out of new storage</p> <p>Limited research and expertise in transition from cryogenic to conventional storage</p> <p>Cost</p> <ul style="list-style-type: none"> <li>– No low hanging fruit</li> <li>– Deliverability needed</li> <li>– Volatility supports</li> <li>– At risk</li> </ul>	<p>Availability of cost-effective storage (salt, depleted reservoir)</p> <p>Effect of surrounding pressures on production from salt caverns</p> <p>Salt cavern brine disposal</p> <p>Lined rock caverns</p> <ul style="list-style-type: none"> <li>– Tunneling techniques</li> </ul>	<p>Greater use of multi-laterals: cost vs. short term benefits</p> <p>Horizontal drilling technology for hard rock reservoirs</p>	<p>Ability to make integrity decisions for aging infrastructure</p> <p>Determining gas loss and migration beyond dry hole perimeter</p> <p>Low cost, nonintrusive method of measuring downhole cathodic protection</p>

**CONVENTIONAL GAS STORAGE – GROUP A**  
**Exhibit 3.1.2 R&D Needs to Overcome Barriers**  
Most Critical R&D Needs: ★ = High Priority Vote ● = Priority Vote

Reservoir Characterization		Reservoir Management	Gas Processing	Damage at Wellbore and Injectivity	Remote Sensing and Control
<p>Seismic technology applications</p> <ul style="list-style-type: none"> <li>Working gas/Base gas ratio improvement</li> <li>Accurate characterization using 3-D seismic simulator</li> <li>Monitor reservoir</li> <li>Illuminate periodically</li> <li>Implement plan ★★★★★</li> </ul> <p>Develop alternative to surface seismic to identify by-passed gas</p> <ul style="list-style-type: none"> <li>Minimize impact on community</li> <li>Low cost/quick ★★●●</li> </ul> <p>Tie in real time pressure/rate data to build computer reservoir model ●●</p> <p>Better/lower cost cross-well seismic</p> <p>Research into techniques that enable seismic data to be reprocessed to identify reservoir characteristics</p> <p>Develop better numerical simulators to handle heterogeneities—hybrid FD/FE/BE simulators ●●</p>	<p>Development of process that combines geophysical in-situ and lab testing with proper models to characterize rock mass ●</p> <p>Laboratory study of permeability hysteresis for gas flow ●</p> <p>Test and analysis progress to deformation near wellbore coupled mechanical/fluid deformation short/long term ●</p> <p>Understanding of transition between continuum – discontinuum response of rock mass time and length-scale ●</p> <p>Develop cheaper rotary sidewall coring tool that reliably operates in air and in hard rock without overheating (and in cased hole) ●</p> <p>Research/fabrication/ testing of smaller more flexible logging tools for use in horizontal well bores ●</p> <p>Application of ground penetrating radar</p>	<p>Reversible downhole barrier to gas migration (foam, polymers) ★★★★★</p> <p>Explore using reservoir limits test technologies to replace S/I's for inventory monitoring ●●●●●</p> <p>Remote sensing of migrated gas ●●●●●</p> <p>Computer model to accurately predict inventory—no shut-in required ●</p> <p>Study dual-use of storage—liquid and gas, seasonal?</p>	<p>Develop means of preventing/dealing with hydrates formed during operations ★★★★★</p> <p>Reduce cost of wellhead filtration ●●●●●</p> <p>Better final cleaning procedure for the injecting steam—electrostatic? Or any other ●</p> <p>Designing and testing of hydrogen removal equipment geared to smaller storage operations</p> <p>Reduce cost of compression</p>	<p>Sampler or recorder to determine type and extent of wellbore damage ★★</p> <p>Develop testing methods for skin damage determination in caverns as opposed to wells (caverns and wells) ●●●</p> <p>Prevention of damage</p> <ul style="list-style-type: none"> <li>Recommendation/ best practice already in existence</li> <li>Study for damage issues not dealt with by best practices/economics ●●●</li> </ul> <p>Prevent deliverability loss due to water encroachment (relatively permanent damage) ●●</p>	<p>Electronic flow measurement – non-intrusive rate measuring device that does not require extensive facilities and can handle multiple phases ★★★★★</p> <p>Downhole pressure measurement-develop wireless communication technology that requires minimal energy so downhole sensors can communicate with surface recorders over extended periods (months, years) ●●●</p> <p>Electronic flow measurement-communication -cheaper, more reliable communication technology that does not require line-of-sight for communication ●</p> <p>Less expensive instrumentation/ control equipment for reservoir management</p>

**CONVENTIONAL GAS STORAGE – GROUP A**  
**Exhibit 3.1.2. R&D Needs to Overcome Barriers (continued)**  
**Most Critical R&D Needs: ☼ = With Major R&D Component   ● = With Minimal R&D Component**

Salt/Rock Caverns	Integrity	Drilling Technology	Other
<p>Proof of concept scale test heat transfer of LNG to brine ☼●●●●●</p> <p>Develop new salt production (from brine) technologies ●●</p> <p>Research tunneling in other countries ●</p> <p>Alternative method to remove salt for cavern formation—heat?</p> <p>Develop brine concentration method to reduce injection volume (inexpensive)</p>	<p>Better means of assessing remaining strength. Better means of measuring metal loss. ☼☼●●●●●</p> <p>Device to measure current flow downhole. Application of pipeline current mapping device ●</p>	<p>Reduce cost of drilling workovers — Lasers? — Conventional ●●●</p> <p>Horizontal drilling in hard rock</p> <p>Directional hammer bit with</p>	<p>Expedited processing of governmental approvals for pipeline expansions</p> <p>Promotion of frontier supply areas (and improved drilling techniques) to provide adequate supply for injection.</p>

**CONVENTIONAL GAS STORAGE – GROUP A**  
**Exhibit 3.1.3. Implementation Strategy**

<b>R&amp;D Priority</b>	<b>Component R&amp;D Activities and Steps</b>	<b>Capabilities, Tools, Facilities, and Resources</b>	<b>Collaborations, Partners, Government Role</b>	<b>Geographic Benefits</b>	<b>Impact (0-5)</b>
Use seismic and alternative technologies for better reservoir characterization and monitoring for better working gas to base gas ratio	Develop full cycle model Benchmark/Baseline review Hardware development Software development Research on more controllable seismic sources Improve resolution Tailor to natural gas storage needs Build simulator Integrate current industry technologies to attack problem Non-surface seismic=>alternative, non-invasive	Candidate reservoir Geophysicists Modeling expertise Remote sensing capabilities	Universities => interpretation Industry: storage (data) Geophysical companies Oil/E&P companies Military expertise (national/defense labs) Government Role — Funding — Technology sharing	Widespread Largest: areas w/ existing reservoirs and some new	Deliverability/Cycling = 3.5 Cost Savings = 4.5 Safety and Security = 1 Capacity = 5 Environmental = 1.5 Reliability = 3
Develop a downhole barrier to gas migration	Study barrier placement Location criteria Material/chemical studies Accurate reservoir characterization Monitoring techniques	Physical chemistry expertise Lab testing Test reservoir	Storage operating company Academia Well service companies Chemical companies Waste remediation companies Government Role — Funding — Apply waste experience (technology sharing)	Widespread Especially aquifer operations	Deliverability/Cycling = 2 Cost Savings = 3.5 Safety and Security = 3 Capacity = 5 Environmental = 3 Reliability = 3

**CONVENTIONAL GAS STORAGE – GROUP A**  
**Exhibit 3.1.3 Implementation Strategy (continued)**

<b>R&amp;D Priority</b>	<b>Component R&amp;D Activities and Steps</b>	<b>Capabilities, Tools, Facilities, and Resources</b>	<b>Collaborations, Partners, Government Role</b>	<b>Geographic Benefits</b>	<b>Impact (0-5)</b>
Develop a method to prevent/handle hydrates formed during operations	Basic chemistry & thermodynamic studies Computational flow/fluid dynamics Sensing technologies Phase behavior	Basic chemistry Lab test facilities Flow loop Field test	CFD consortium Chemical companies Academia/universities Storage field operator Government Role — Funding — Technology sharing	Especially cold climates High pressure reservoirs	Deliverability/Cycling = 2.5 Cost Savings = 3 Safety and Security = 3.5 Capacity = 0 Environmental = 0 Reliability = 5
Develop brine disposal method	Disposal studies Alternative uses/by-products Small volume salt production Geologic studies Technology adoption/transfer	New salt production technology Geologic studies Geologic characterization Reservoir characterization	Salt industry Gas storage operators Liquid storage operators Oil producers Government Role — Funding — Government regulatory cooperation — Incentives — Facilitator	Northeast (W. NY, W. PA) Michigan Central AZ	Deliverability/Cycling = 4 Cost Savings = 5 Safety and Security = 0 Capacity = 2 Environmental = 2 Reliability = 0
Develop method to better assess metal loss and remaining strength	Look at line pipe studies Process piping thickness surveys Metallurgy studies Gather info/data from operators that have done studies Burst testing	Correlation modification to fit downhole pipes Lab to perform burst test	Storage field operator Well service companies Corporate/industry labs Universities National labs Regulatory assistance Collaboration with national labs Funding Objective evaluation of cap.	Widespread	Deliverability/Cycling = 1 Cost Savings = 4 Safety and Security = 4.5 Capacity = 0 Environmental = 4.5 Reliability = 4

## 3.2 CONVENTIONAL GAS STORAGE – GROUP B

This group was charged to address research needs in the area of conventional natural gas storage. The group accomplished this by creating the following three products:

- Barriers to improve conventional natural gas storage,
- Research and development needs and opportunities to overcome the barriers, and
- Implementation strategies for the highest priority research and development needs.

The group's composition was well balanced by managerial and technical representatives from industry, government, and universities. Support for the group diversity was noted; generally contacts are only made among individuals in similar positions. A positive synergy developed as not only products were developed, but information was also exchanged. This "educating" of the group assisted in brainstorming. Once everyone had an understanding of major topic areas, ideas flowed more smoothly.

The first brainstorming session focused on the barriers to improve conventional natural gas storage. Then the group organized the barriers into the following categories: Reservoir Characterization, Market Uncertainty/Risk, Integrity, Existing Facilities, Regulations, and Other. The complete results for this product are given in Exhibit 3.2.1.

The group then brainstormed on research and development needs and opportunities to overcome the barriers to improve conventional natural gas storage. Again, the group organized the needs into categories: Education and Technology Transfer, Existing Facility Optimization, Regulation, Reservoir Characterization, and New Technologies. The group was given the opportunity to vote using one highest priority vote and four general votes. Based on group consensus, the highest priority needs would become the basis for implementation strategies to be detailed by the participants. The group also arranged the needs into time frames based on when the impacts of the accomplishment of the need would be felt by the industry: Short Term (0 – 5 years), Mid-Term (5 – 10 years), and Long-Term (10 – 15 years). The complete results of this product can be found in Exhibit 3.2.2. The following four research and development needs were the top vote-getter topics and thus formed the basis for the implementation strategies:

- Integrity: Develop advanced casing inspection tools capable of characterizing pipe condition,
- Develop new methods for creating storage reservoirs,
- Evaluate current reservoir capacity and deliverability, and
- Automated field operating systems.

### Participants: Conventional Gas Storage – Group B

NAME	ORGANIZATION
Steve Bergin	ONEOK
Jim Blasingame	Dominion Transmission
Bob Bretz	New Mexico Tech
Ryan Connors	Equitable Utilities
Rick Daniel	Alberta Energy Company
Joe Frantz	Hoblitch-Reservoir Technologies
Rick Gentges	El Paso Corporation
Mark Gredell*	Duke Energy North America
John Guoynes	Halliburton Energy
Paul Harris	GDF Energy, Inc.
Will Johnson	Visage Energy Group
Shahab Mohaghegh	Intelligent Solutions, Inc.
Thomas Mroz	NETL
Larry Myer	LBNL
Larry Pekot	Advanced Resources International
Gary Sames	NETL

\*Report out presenter

**FACILITATOR:** Alicia Dalton, Energetics

**WRITER:** Josh Chaddock, Energetics



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For each topic, the group identified component research and development activities and steps; capabilities, tools, facilities, and resources; collaborations, partners, and the government's role; and geographical benefits. The participants also reached consensus on the impact level that each priority need could have on a given set of factors: deliverability/cycling, cost savings, safety and security, capacity, environmental, and reliability. Scores for impact were given from zero to five, corresponding to no impact to the utmost impact, respectively. The implementation strategies can be viewed in their entirety in Exhibit 3.2.3.

During brainstorming, many new ideas were generated, out of the box thinking occurred, and group consensus was reached. But several ideas and discussions surfaced that may not be completely represented in the products.

- Throughout the day, the group stressed the problems associated with the “legacy” of regulation and that it proved to be quite a hindrance for natural gas storage. Since a focus of this particular workshop was research and development opportunities, little could be done in the area of regulations, but the group did want to stress its importance.
- Questions were raised about the government's role and who should effectively take the lead in many of the implementation strategies. Overall, it was determined that the government successfully has functioned as a facilitator hosting workshops to bring together diverse groups of storage professionals, and that such a role should continue. The participants also noted that the government could be instrumental in funding and technology transfer.
- Several participants had views regarding aquifer storage versus other means of conventional gas storage. The support for aquifer use was not felt as strongly by industry as by academia in this particular session.

Although “Develop new methods for creating storage reservoirs” received the second highest priority ranking, during the implementation strategy it was discovered that little impact on the industry would result from its success. No impact score higher than 2.5 was given in the implementation strategy (see Exhibit 3.2.3). A discussion ensued resulting in a group consensus that although the need received significant votes, its impact on conventional natural gas storage would be minimal.

**CONVENTIONAL GAS STORAGE – GROUP B**  
**Exhibit 3.2.1 What are the Barriers to Improve Conventional Gas Storage?**

<b>Reservoir Characterization</b>	<b>Market Uncertainty/ Risk</b>	<b>Integrity</b>	<b>Existing Facilities</b>	<b>Regulations</b>	<b>Other</b>
<p>Extending peaking ability from conventional reservoirs</p> <p>Some converted wells are not properly spaced; optimum well spacing</p> <p>Lack of production methodology for water/gas flow in aquifer storage</p> <p>Need better brine disposal</p> <p>Lack of method of brine water disposal for salt projects</p> <p>Need for information and analysis quicker; data availability</p> <p>Need to get expertise in reservoir model in right hands</p> <p>Lack of reservoir characterization</p> <p>What is real reservoir capable of performing?</p> <p>Lack of integrated geologic, reservoir, and performance data</p> <p>Coupled reservoir simulation, i.e., reservoir, wellbore pipeline, facilities</p> <p>Lack of suitable reservoirs (new reservoirs)</p> <p>Lack of quality data</p> <p>Damaged reservoirs (wells)</p>	<p>Geographical locations of suitable reservoirs</p> <p>Limited in new projects by available quality depleted gas reservoirs</p> <p>Some technology options are high risk</p> <p>Market uncertainty</p> <p>Difficulty valuing existing regulated assets</p> <p>Cushion gas cost</p>	<p>Lack of methodology to accurately (and economically) measure stress (delta-pressure)</p>	<p>Strength of materials and regulatory limits on safe operations practices</p> <p>Need models for entire system</p> <p>No strength of materials models for existing wells</p> <p>Age of existing facilities—limits the options available to re-engineer asset</p> <p>Aging infrastructure originally designed for seasonal service</p> <p>Surface and pipeline constraints</p> <p>Pipeline capacity from storage “island” to the market</p> <p>Lack of flexibility of field/well operations</p>	<p>The legacy of regulation</p> <p>Regulatory uncertainty</p> <p>Utilities lack incentives</p> <p>Lack of regulatory clarity for shifting assets out of regulation</p> <p>Reservoir pressure limitations—limited in most states by discovery pressure</p>	<p>Concise collaborative technology initiative</p> <p>Limited technical manpower talent</p> <p>Technology not up with the times</p> <p>Lack of technology man hours (for simulation)</p> <p>Technology transfer</p>

**CONVENTIONAL GAS STORAGE – GROUP B**  
**Exhibit 3.2.2 What are the R&D Opportunities/Needs to Overcome the Barriers?**  
**Most Critical R&D Needs: ☆ = High Priority Vote ● = Priority Vote**

Timeframe	Education and Technology Transfer	Existing Facility Optimization	Regulation	Reservoir Characterization	New Technologies
<b>SHORT-TERM (0-5 YEARS)</b>	<p>Other - encourage/ foster closer government/industry technology research initiative ●●●●●</p> <p>Educate U.S. consumer, business, government, and financial world on storage industry, regulations, and barriers</p> <p>DOE to act as liaison with regulators to reinforce industry opinions on the safety of underground gas storage practices</p> <p>DOE to continue to serve as collaborative technology forum to bring storage operators together with research initiatives</p>	<p>Automated field operating systems ●●●●●●●●</p> <p>Research into geo-mechanical predictive mechanisms in conventional gas storage reservoirs ☆●●</p> <p>Identify the right data to collect (identify performance drivers) ●●●</p> <p>Reengineering of baseload fields for higher value services ●●●</p> <p>Develop technologies that allow for re-entry into existing well bore for recompletion in a better quality area of reservoir ●●</p> <p>Develop cost-effective method to produce gas/water in aquifer storage</p>	<p>Storage industry task force on deregulation ●●●</p> <p>Perform risk assessment analysis EH&amp;S ●●</p>	<p>Better coupled reservoir/surface simulators ●●●●●●</p> <p>Evaluate current reservoir capacity and deliverability ☆☆</p> <p>Permanent geophysical monitoring ☆☆●●</p> <p>Integrated geophysics and reservoir modeling ●●</p> <p>Develop simple, quick, integrated data analysis methods ●</p> <p>Develop cost-effective data collection strategy ●</p>	<p>Integrity: Develop advanced casing inspection tools capable of characterizing pipe condition ☆☆☆☆●</p> <p>Develop new methods for creating storage reservoirs ☆☆☆☆</p> <p>Market Uncertainty/ Risk: Develop tools/products to evaluate base gas alternatives (lower cost) ●●●●● — Use of inert cushion gas</p> <p>Integrity: Develop methods to accurately calculate stress from existing logs ☆☆</p> <p>Research suitability of unconventional reservoirs (i.e., deep, fractured) ●</p> <p>Improved data management system ●</p> <p>Develop new technology to assist engineers and managers make better decisions — Lined rock cavern for areas with no salt or reservoir</p> <p>Improve methods for inventory verification</p>
<b>MID-TERM (5-10 YEARS)</b>			<p>Redesign regulatory framework ●●</p>	<p>Permanent geophysical monitoring ☆☆●●</p>	<p>Utilize hydrates as storage medium</p>
<b>LONG-TERM (10-15 YEARS)</b>					<p>New methods for brine disposal and use ●</p>

**CONVENTIONAL GAS STORAGE – GROUP B**  
**Exhibit 3.2.3 Implementation Strategy**

R&D Priority	Component R&D Activities and Steps	Capabilities, Tools, Facilities, and Resources	Collaborations, Partners, Government Role	Geographic Benefits	Impact (0-5)
<b>#1</b> Integrity: Develop advanced casing inspection tools capable of characterizing pipe condition	<p>Evaluation of current tools</p> <p>Evaluation of integrity of multi-concentric strings</p> <p>Further development of current tasks</p> <p>Design parameter characterization</p> <p>Develop correlations between log interpretations to strength of materials to determine wellbore integrity</p>	<p>Oil Field Service Co—have ability to do tool research</p> <p>Southwest Research</p> <p>Battelle</p> <p>Gaz de France</p>	<p>Service companies (Tool development lead)</p> <p>Operators (lead)</p> <p>Laboratories (lead)</p> <p>University</p> <p>American Petroleum Institute</p> <p>Interstate Oil &amp; Gas Compact Commission (IOGCC)</p> <p>ASME</p> <p>SPE – Society of Petroleum Engineers</p> <p>Collaboration Types</p> <ul style="list-style-type: none"> <li>— Joint research ventures</li> <li>— Committees</li> </ul> <p>Government Role</p> <ul style="list-style-type: none"> <li>— Organize</li> <li>— \$</li> <li>— Technology transfers</li> <li>— Facilitate</li> </ul>	Everywhere	<p>Deliverability/Cycling = 4</p> <p>Cost Savings = 4</p> <p>Safety and Security = 5</p> <p>Capacity = 0</p> <p>Environmental = 4.5</p> <p>Reliability = 4</p>

**CONVENTIONAL GAS STORAGE – GROUP B**  
**Exhibit 3.2.3 Implementation Strategy (continued)**

<b>R&amp;D Priority</b>	<b>Component R&amp;D Activities and Steps</b>	<b>Capabilities, Tools, Facilities, and Resources</b>	<b>Collaborations, Partners, Government Role</b>	<b>Geographic Benefits</b>	<b>Impact (0-5)</b>
<b>#2</b> Develop new methods for creating storage reservoirs	Continue work on lined rock caverns  Regional geologic feasibility cost benefit studies  Thermal re-excavation  New aquifer methods  New sealing methods  Cost reduction (liquefaction)  Abandoned coal mines  Higher Btu content	National Labs  Geological societies (USGS)  Universities  AAPG  Service companies  DOD drilling techniques  ARMA  A&E Co.  API for Btu	USGS  State geological societies  University  Service companies  Operating companies  Construction companies  Joint research ventures  Conservation  Joint business ventures  State agencies  Government Role – \$ – Research – Coordination – Technology transfer Government leads with USGS	New England  Mid-Atlantic  South East  Creates a new “everywhere”	Deliverability/Cycling = 1 Cost Savings = 1 Safety and Security = 0 Capacity = 1 Environmental = 1 Reliability = 2.5
<b>#3</b> Evaluate current reservoir capacity and deliverability	Quantify effect of damage on deliverability  Impacts of lost gas  Identify source of damage  Geomechanical integrity  Optimize reservoir performance  Advanced data interpretation  Update/advance reservoir characterization	Service companies  Universities  Consultants  Operators  National Labs  Tool well test analysis  Geologic reservoir models  Reservoir simulation  Artificial intelligence  Methods of advanced data collection	DOE  Private industry  Operators  Consultants  Universities  Labs  Government Role – None? – \$ – Coordination – Technology transfer	Everywhere (new and old)	Deliverability/Cycling = 5 Cost Savings = 5 Safety and Security = 1.5 Capacity = 5 Environmental = 3 Reliability = 5

**CONVENTIONAL GAS STORAGE – GROUP B**  
**Exhibit 3.2.3 Implementation Strategy (continued)**

<b>R&amp;D Priority</b>	<b>Component R&amp;D Activities and Steps</b>	<b>Capabilities, Tools, Facilities, and Resources</b>	<b>Collaborations, Partners, Government Role</b>	<b>Geographic Benefits</b>	<b>Impact (0-5)</b>
<b>#4</b> Automated field operating systems	Survey existing practices Cost effective instrumentation Communication technology Data storage/management Data integration Data mining and analysis Artificial intelligence Scope = include pipeline to reservoir Maintenance and reliability of existing systems	Service companies Implementation firms Software data developers Industry Process control Communication companies Demonstration sites	Industry Service companies Operators Consultants Universities Labs Software companies Instrumentation people Collaboration Types – Develop technology – Collaborative/Cooperative agreements Government Role – Technology transfer – Coordination – \$	Everywhere	Deliverability/Cycling = 3 Cost Savings = 4 Safety and Security = 5 Capacity = 0.5 Environmental = 2 Reliability = 5

### 3.3 GAS STORAGE FOR POWER GENERATION & REMOTE OFF-PIPELINE

Projections of future storage needs and increased gas consumption targets were of little value to the group. The only salient points were the need for high deliverability and new storage locations and options like CNG. Most important was the fact that injectability is the primary concern, more so than deliverability. Nearly all R&D would be for a near-term 0-5 year time horizon. There was a consensus to use existing E&P techniques by turning them around for injectability. Given the importance of salt caverns for deliverability, a top priority is to monitor and analyze their long-term integrity. By examining case studies of failures, design improvements can be made on the front end of construction. Another priority is the need to somehow get the Federal Energy Regulatory Commission (FERC) to grant regulator relief to storage aspects, especially for expansion at utility storage sites.

The ability to use an existing storage well for observations, experimentation, and verification is very cheap compared to drilling a new well and should be pursued. Moreover, the risk of failure for new storage wells cannot be absorbed and is deterring investment. Another costly aspect is the compression requirement for additional gas in salt mines. LNG is also expensive, and on-site liquefaction is not fast enough for power delivery. So, the economic benefits to power consumers from enhanced storage infrastructure should be modeled, optimized, demonstrated, and publicly reported.

#### Participants: Gas Storage for Power Generation & Remote Off-Pipeline

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#### BARRIERS AND ISSUES

Barriers feedback from the group was easily categorized under five major headings: injectability cycling, regulatory, capital risk, remoteness and location, and technical risk. Injectability is a larger problem than deliverability, especially for conventional storage in the Rocky Mountains and the Northeast. Some of the easiest engineering expansion projects for utilities cannot be done because of regulatory barriers. Capital risk issues stem from the lack of any rate base spreading and liquidity during high demand; the market mechanisms are just not there. Brine disposal is a prevalent inland problem away from seashores.

#### OPPORTUNITIES

The R&D opportunities used the same topic headers from barriers, and added an environmental restriction category. Participants prioritized opportunity needs using one top vote and four regular votes. Under technical risk, the need for long-term integrity of bedded salt caverns information was the only one to receive three top votes. Two other needs received a total of 6 votes: FERC 7C relief and CNG solutions. Another two needs received two top votes and two regular votes: reservoir engineering and economic benefit. All of these opportunity needs were carried over to the implementation analysis.

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Time frames for most of the topics were short-term. Cogeneration and distributed generation needs were assessed to be mid-term given the current market. Only the inert gas need was long-term, and it appears that European endeavors are currently addressing this issue. The group did have the foresight to change exotic to novel for R&D needs.

## **ACTIONS**

The group produced lists of activities for each of the top 5 priority opportunities, along with capability requirements, collaborations, geographic benefits, and a set of impact gauges. However, funding requirements were not ascertained. There was a strong emphasis on using existing E&P tools to apply to storage problems by reversing the focus from production to storage. In other words, how can we use the technological advances in E&P to apply to injectability and cycling issues? A technology angle for FERC regulatory relief is imperative to meet NETL R&D requirements.

Collaborations generally will involve storage operator along with E&P and service companies. Government roles in general would be regulatory with involvement for the Environmental Protection Agency and State regulators. Geographic benefits would accrue to anywhere and everywhere there is storage for the most part. CNG solutions would benefit downtown coastal urban areas, and would allow the system to be pressurized from ends to effectively increase capacity.

Impacts gauges oscillated between nearly none to maximum impact. None of the categories was always high or low, though the reliability category was relatively high with an average of four for impact. Conversely, safety and security were for the most part low impacts except for the long-term geotechnical integrity of bedded salt caverns. Cost savings impacts were in the 3 –3.5 range except for CNG solutions.



**GAS STORAGE FOR POWER GENERATION & REMOTE OFF-PIPELINE**  
**Exhibit 3.3.1 What are the Barriers to Improve Gas Storage for Power and Remote Off-Pipeline?**

<b>Injectability Cycling</b>	<b>Regulatory</b>	<b>Capital Risk</b>	<b>Remoteness and Location</b>	<b>Technical Risk</b>
<p>Injectability larger problem than deliverability especially conventional storage reservoirs</p> <ul style="list-style-type: none"> <li>— Especially Rocky Mountain and northeast</li> </ul> <p>Pad gas and working gas</p> <ul style="list-style-type: none"> <li>— Reduce ratio</li> <li>— Inert gas</li> <li>— Recovery</li> </ul> <p>Storage gas cycling for delivery to power generating facilities/gas injection</p> <p>Flexibility— injection/withdrawal at short notice—controls</p> <p>Counter cycling service/reservoir inventory management</p> <p>Reliability</p> <p>The storage needs for peakers different from baseload plants</p> <p>Downstream deliverability of available capacity</p> <p>Balancing power peak requirements with upsets “nominations”</p>	<p>Barrier, no regulatory incentive!</p> <ul style="list-style-type: none"> <li>— Easiest projects cannot be done</li> <li>— Especially utilities with basic engineering</li> </ul> <p>Air emission limitations limits injection compressor emissions</p> <p>Pipeline use:</p> <ul style="list-style-type: none"> <li>— Cost allocation</li> <li>— Industries subsidize IPP’s, LDC’s</li> </ul> <p>Delta pressuring to increase working capacity—regulatory restrictions</p> <p>Public acceptance “NIMBY,” regulatory impediment</p> <p>Relative environmental impact (CO<sub>2</sub>)</p>	<p>Regulatory – capital risk allocation – independent merchant has no rate base to absorb mistakes</p> <p>Reservoir evaluation – staging risk</p> <p>Risk market will overbuild due to regulatory impediments</p> <p>Market liquidity during high demand periods – “it is not available”</p>	<p>Remoteness itself is a barrier. It is economic risk.</p> <p>Security vs. terrorism sensitivity of storage medium</p> <p>Good DG sites usually off-pipeline</p>	<p>Salt cavern brine disposal</p> <p>Geologically constrained areas “no or low deliverability”</p> <p>Resource conservation/loss (shrinkage)</p> <p>Is there a role for onsite LNG storage at power plants? Regulatory, technology, economic barriers</p> <ul style="list-style-type: none"> <li>— Trucking and liquefaction on site</li> </ul> <p>Personnel</p> <ul style="list-style-type: none"> <li>— Training</li> <li>— Experience</li> <li>— Education</li> <li>— Commercial savvy</li> </ul>

**GAS STORAGE FOR POWER GENERATION & REMOTE OFF-PIPELINE**  
**Exhibit 3.3.2 What are the R&D Opportunities/Needs to Overcome the Barriers?**  
**Most Critical R&D Needs: ☆ = High Priority Vote ● = Priority Vote**

Timeframe	Injectability Cycling	Regulatory	Capital Risk	Technical Risk	Remoteness and Location	Environmental Restrictions
<b>NEAR-TERM (0-5 YEARS)</b>	<p>Research into well completions, fracturing, reservoir engineering, better simulation techniques ☆☆●●</p> <p>Research into better control mechanisms to enhance flexibility ☆</p> <p>Alliance with engine/compressor manufacturers for cycling units ●</p> <p>Non-damaging compressor lubricants</p>	<p>Expedited or elimination of FERC 7C relative to risk ☆☆●●●●</p> <p>Economic benefit to power consumers with enhanced storage infrastructure ☆☆●●</p> <p>National asset reevaluation ●●</p> <p>R&amp;D can show magnitude of the engineering opportunity ●</p> <p>Downhole safety valves “screwed” ●</p> <p>Electric Motor Drive (EMD) at storage exempt from power curtailments on interruptible (IT) contracts</p> <p>Research into improved operational efficiency and technologies that preserve national resources</p>	<p>Commercial optimization ●●●</p>	<p>Long-term integrity of bedded salt caverns information ☆☆☆☆</p> <p>Cement quality, bond quality, pipe quality ●●●●</p> <p>— Longevity/safety casing and wellbore design</p> <p>Brine disposal alternatives and opportunities – increase saturations during leeching ●●</p> <p>LNG vaporization technology</p> <p>Focus especially operations/tools to storage development</p>	<p>CNG and other solutions ☆☆●●●●</p> <p>Better ways to look inside salt ●●●●</p> <p>Facility safety/security report ●</p> <p>Distributed generation vs. central station infrastructure requirements R&amp;D</p>	<p>Compressor environmental performance</p> <p>Risk of SCR application to gas storage</p>
<b>MID-TERM (5-10 YEARS)</b>	<p>Variable speed compressor ●●</p>		<p>Other value added solutions, e.g., cogeneration ●●</p> <p>Better and cheaper reservoir modeling</p>	<p>Gas cleanup for H<sub>2</sub>O/CO<sub>2</sub> in LNG process and gas liquids</p>	<p>Novel R&amp;D ☆☆●●</p> <p>New, tools for cheap screening new formation ●●</p> <p>Distributed Generation R&amp;D must include storage options ●●</p> <p>Assessment of underground reservoir traps</p>	<p>Gas migration assessment and abandonment ●●</p>
<b>LONG-TERM (10-15 YEARS)</b>				<p>Use of inert gas for PAD gas ●●●</p>		

**GAS STORAGE FOR POWER GENERATION & REMOTE OFF-PIPELINE**  
**Exhibit 3.3.3 Implementation Strategy**

<b>R&amp;D Priority</b>	<b>Component R&amp;D Activities and Steps</b>	<b>Capabilities, Tools, Facilities, and Resources</b>	<b>Collaborations, Partners, Government Role</b>	<b>Geographic Benefits</b>	<b>Impact (0-5)</b>
<b>#1</b> Long-term geotechnical integrity of bedded salt caverns, e.g., roof leaks, deformation	Geologic analysis  Failure analysis and definition  Monitoring feedback for better front end	Casing design E&P tool, lab tests, database raise it to a safety issue	Among industry  SMRI, GTI, DOE/SPR, NYSERDA, academia, government-public meetings	Appalachia, Canada, Central Mid-West, Northern Mexico	Deliverability/Cycling = 1.5 Cost Savings = 3 Safety and Security = 5 Capacity = 5 Environmental = 4 Reliability = 5
<b>#2</b> CNG and other solutions, remote application needle peak, DG support	Demonstration  Marketing feasibility study  Regulatory support  Security aspect education	Equip designers, end-users, pilot plant	Storage developer and power generator and end user industry  Government-regulatory standards and funding	Anywhere in rural and urban downtown  Double pipeline capacity downtown and coastal urban — Feed both ends of loop	Deliverability/Cycling = 5 Cost Savings = 1 Safety and Security = 2 Capacity = 1 Environmental = 4.5 Reliability = 5
<b>#3</b> Expedited or elimination of FERC 7C relative to risk	Independent study  Experimental well by the operator/risk taker  Assessment of opportunity and risk	Education and workshop  E&P tools  Active role by service companies	E&P and service companies and storage operator  State government, EPA	Everywhere. Good for salt and reservoir	Deliverability/Cycling = 4.5 Cost Savings = 3.5 Safety and Security = 2 Capacity = 5 Environmental = 1 Reliability = 4
<b>#4</b> Research into well completions, fracturing, reservoir engineering, better simulation techniques for injectivity timing	Apply E&P tools to study going other way for injection. Focus on storage vs. production. Reservoir engineering model	Use existing field for pilot studies  Reservoir engineering model match	Storage operators and service and E&P  State regulators, and EPA	Anywhere reservoir storage	Deliverability/Cycling = 5 Cost Savings = 3 Safety and Security = 1 Capacity = 4 Environmental = 1 Reliability = 4.5
<b>#5</b> Economic benefit to power consumers with enhanced storage infrastructure replace long-haul firm transport (FT)	Sensitivity analyses  Demonstration at peaker and CC  Review existing studies	Models (fuel) — Pipeline — Dispatch — Storage  Result is economic model showing optimization for commodity and transportation	ISO regional studies  OED at FERC (Office of Economic Development)  Pipeline and storage companies	Any marketing company in U.S.  Any IPP	Deliverability/Cycling = 1 Cost Savings = 3.5 Safety and Security = 0 Capacity = 3.5 Environmental = 1 Reliability = 2.5